(2)

NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

COMPARISON OF GRAPHICAL TERRAIN RESOLUTIONS BY SCENARIO FOR THE JANUS(A) COMBAT MODEL

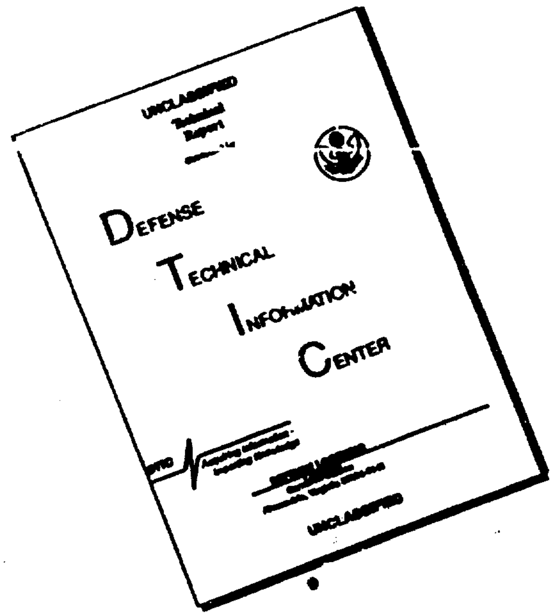
by

David J. Toy

March, 1992

Thesis Advisor: Donald R. Barr
Co-Advisor: Captain Dennis D. Bundy, USA

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b. OFFICE SYMBOL (If applicable) 36	7a. NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000	7b. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS Program Element No. | Project No. | Task No. | Work Unit Accession Number

11. TITLE (Include Security Classification)
COMPARISON OF GRAPHICAL TERRAIN RESOLUTIONS BY SCENARIO FOR THE JANUS(A) COMBAT MODEL

12. PERSONAL AUTHOR(S) Toy, David J.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (year, month, day)	15. PAGE COUNT
Master's Thesis	From To	MARCH 1992	45

16. SUPPLEMENTARY NOTATION
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17. COSATI CODES			18. SUBJECT TERMS (continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUBGROUP	Simulations, Modeling, Combat, JANUS

19. ABSTRACT (continue on reverse if necessary and identify by block number)

The purpose of this thesis is to investigate effects of the graphical terrain resolution of the graphical terrain resolution of the Janus(A) Combat Model. Two scenarios were compared at differing terrain resolutions in order to determine if the resolution affects results of the simulation. Several measures of effectiveness (MOEs) were used in the study. The results suggest terrain resolution used in Janus(A) of Fort Hunter-Liggett does not impact greatly on the outcome of the simulations of two ground combat scenarios for most MOEs. However, there is enough evidence to suggest that further investigation of graphical terrain resolution should be conducted at higher resolutions.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS REPORT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Donald R. Barr	22b. TELEPHONE (Include Area code) (408)646-2763 22c. OFFICE SYMBOL MA-BA

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted
All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

Approved for public release, distribution is unlimited.

Comparison of Graphical Terrain Resolutions
By Scenario for the Janus(A) Combat Model

by

David J. Toy
Captain, United States Army
B.S., California State University, Sacramento

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN INFORMATION SYSTEMS

from the

NAVAL POSTGRADUATE SCHOOL
March 1992

Author: David J. Toy

David J. Toy

Approved by: Donald R Barr

Donald R. Barr, Thesis Advisor

Dennis D. Bundy

Dennis D. Bundy, Co-Advisor

Tung Bui

Tung Bui, Second Reader

David Whipple, Chairman
Department of Administrative Sciences

ABSTRACT

The purpose of this thesis is to investigate effects of the graphical terrain resolution of the Janus(A) Combat Simulation Model. Two scenarios were compared at differing terrain resolutions in order to determine if the resolution affects results of the simulation. Several measures of effectiveness (MOEs) were used in the study. The results suggest terrain resolution used in Janus(A) of Fort Hunter Liggett does not impact greatly on the outcome of the simulations of two ground combat scenarios for most MOEs. However, there is enough evidence to suggest that further investigation of graphical terrain resolution should be conducted at higher resolutions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A. GENERAL

Modern combat modeling provides the ability to support the testing of new weapons systems by simulating the environmental and operational conditions under which the systems are tested. This requir.s the model to be patterned after the terrain on which the equipment is planned to be tested. Janus Army (A), a combat simulation model designed for the U.S. Army, offers varying graphical terrain resolutions to the modeler [Ref. 1:p. 8]. Resolution describes the amount of terrain detail which will be incorporated into the model. The terrain is represented graphically in the model.

In his thesis "**Comparison of Tank Engagement Ranges from an Operational Field Test to the Janus(A) Combat Model**", Captain Allen East recommends an "analysis of engagement ranges in Janus(A) using terrain resolution lower than 50 meters [Ref. 2]." Captain East made this recommendation based upon his analysis which showed that Janus(A) consistently generated longer engagement ranges than found in operational field tests. He pointed out that the difference may be due to differences between the Janus(A) terrain database and the actual terrain.

A statistical analysis was performed as part of this thesis to investigate the effects of graphical terrain resolution of the Janus(A) Combat Simulation Model. The effect of terrain resolution on weapons systems' ability to see one another, line-of-sight, was analyzed as well.

Modeling technology exists at Fort Hunter Liggett which can support a one meter terrain resolution. One meter terrain resolution provides the modeler with more detailed terrain (1 meter by 1 meter) than is presently available in Janus(A) database. The question arises as to whether the available terrain resolutions provide sufficient resolution for present and future modeling, and if so, at what dollar cost. A Training and Doctrine Analysis Command, Monterey (TRAC-MTRY) Study Fact Sheet states that current terrain resolutions may be inadequate and suggests using one meter terrain resolution in the near future [Ref. 3].

The analyses performed for this thesis showed that the level of terrain resolution may not have a significant overall affect on the outcome of the simulations conducted in Janus(A). However, in one instance the outcome of the simulations was affected. Investigation of the effects of using differing resolutions should continue. Investigation of the usefulness and cost effectiveness of one meter terrain resolution is recommended. These recommendations are based upon the findings of possible variations in ranges to first engagements for the simulation runs with 12.5 meter and 100 meter terrain resolutions.

B. MODEL-TEST-MODEL

Mr. Walter W. Hollis, Deputy Under Secretary of the Army (Operations Research) has tasked the Army to provide "continuous commitment to improving the modeling process [Ref. 4]." Model-Test-Model (M-T-M) is a concept designed to exploit both combat simulation modeling and field testing such as that conducted by the Testing Experimentation Center (TEC) at Fort Hunter Liggett. The M-T-M process involves several phases ranging from pretest modeling to post-test acceptance of the model [Ref. 5]. The concept includes conducting pretest combat simulation modeling prior to a field test to gain information useful in designing a field test. Such information may play a key role in determining whether test objectives will be met with the proposed test. This thesis is limited to considerations relating to the pretest modeling phase.

C. SCENARIO DEVELOPMENT

1. Scenario Selection

An approved pretest scenario designed for the Abrams M1A2 Early User Test & Evaluation (EUTE) was selected for use in the thesis [Ref. 6]. The deliberate defense scenario chosen was one of four approved by the Armor Center, see Table I. This scenario was selected because the size of the main battle area allowed forces to be deployed in a 7.5 kilometer by 7.5 kilometer area. The scenario also offered differing types of terrain and vegetation. The scenario was altered, two scenarios, in order to test effects of graphical terrain resolution with routes over substantially different terrain. Except for the scenarios and levels of resolution employed in Janus(A), all other controlable variables were held constant.

TABLE I AVAILABLE SCENARIOS

APPROVED JANUS(A) PRETEST MODELING SCENARIOS FOR M1A2 EUTE	
Meeting Engagement	Two advancing units engage on battlefield
Deliberate Defense	One unit prepares defense and waits for attack by opposing force
Deliberate Attack	One unit conducts detailed planning and attacks opposing force
Hasty Defense	Force under attack or about to come under attack quickly sets up in a unprepared defensive posture

2. Forces

In the deliberate defense the blue force, consisting of four M1A2 tanks, was placed in a defilade position on a hilltop overlooking the route over which the opposing force would travel. The blue force could move out of its defilade positions, detect, acquire, and fire at the opposing force. The blue force systems acted independently of one another, so each tank detected, acquired, and fired without regard to the other members of the blue force.

The opposing red force consisted of ten Future Soviet tanks (FST) and four armored personnel carriers (BMPs). The red force was required to travel along a specified route past the blue force's positions. The red force had the capability of detecting, acquiring, and firing on the blue force.

3. Routes

The original route for the scenario was modified creating two routes of advance for the red force and thus two scenarios. The original route (Scenario One) entailed the red force moving along a valley with very little cover and concealment provided by the terrain. The terrain across which the red force advanced was relatively flat. It included only minor hills which could limit the blue force's line-of-sight of the red force.

Figure 1 illustrates the route of advance for the red force (Scenario One). The red force is located at the bottom right hand corner of the figure. The routes of advance for the red force systems are indicated by the broken lines. The triangles are nodes which show a change in the direction of the system.

The route in Scenario Two included hilly terrain that often obscured line-of-sight between the blue forces. The route insured that the red force would still pass in front of blue force as in Scenario One. Figure 2 illustrates the route of advance in Scenario Two.

Figure 1 Scenario One Route of Advance (scale 7.5 kilometers x 7.5 kilometers)

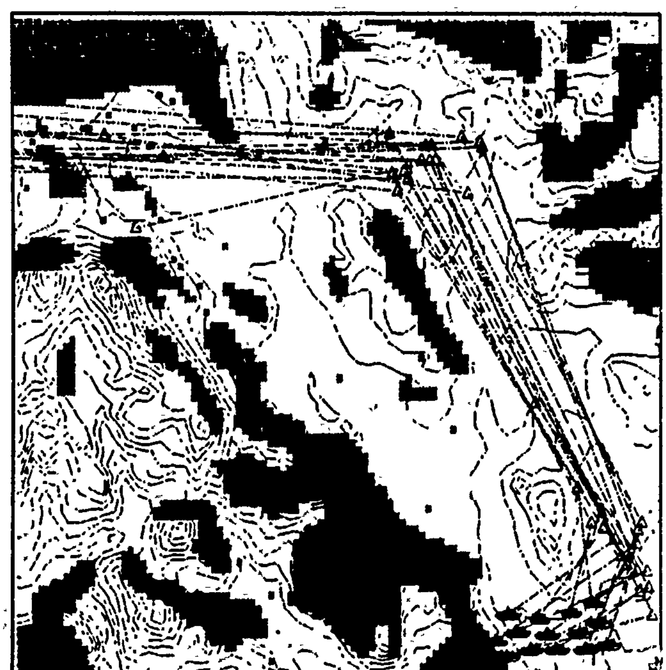


Figure 2 Scenario Two Route of Advance (scale 7.5 kilometers x 7.5 kilometers)

D. MEASURES OF EFFECTIVENESS (MOE)

Measures of effectiveness were selected for use in examining if there are any significant differences using differing terrain resolutions. The MOEs are illustrated in Table II and described below.

TABLE II MEASURES OF EFFECTIVENESS

MEASURE OF EFFECTIVENESS	UNITS
Range to First Detection	Meters
Range to First Engagement	Meters
Range to First Kill	Meters
Shots to Kill	Numerical Count
Shots on Target	Numerical Count

1. Range to First Detection

The range to first detection is the range at which the first red system was detected, either by optical or thermal sensors with which blue systems were equipped.

2. Range to First Engagement

The range to first engagement is the range at which the initial round of the trial is fired by the blue force at a system of the red force.

3. Range to First Kill

The range to first kill is the range at which the first red force system was destroyed by a round fired by the blue force.

4. Shots to Kill

This is the number of shots fired by the blue force at the red force during the trial up to and including the shot which led to the first red system's destruction.

5. Shots on Target

This MOE is the number of shots fired by the blue force at the red system that became the first kill.

II. JANUS(A) COMBAT SIMULATION MODEL

A. OVERVIEW

The Janus(A) Combat Simulation Model supports the M-T-M concept by providing the Army automated tools to perform pretest modeling and post-test modeling and analysis of operational field test data. Janus(A) does not replace operational field testing of equipment, but can supplement operational field tests by extending test results and providing insight into test design. Janus(A) used in conjunction with operational field tests may save the Army man-hours and dollars by reducing personnel and equipment required for operational testing of equipment. With the prospect of limited funds in the future, the Army may well be placing increasing emphasis on simulations such as Janus(A) to support operational testing.

1. System Capabilities

Janus(A) was developed by United States Army TRADOC Analysis Command White Sands Missile Range (TRAC-WSMR) to support tactical and doctrine analysis, and other Army studies [Ref. 1:p. 1]. It provides an ability to model up to 600 systems per side, which can perform the activities of movement, search, detection, or firing. These are individual systems which may be on the ground or in the air. The systems may be coordinated so as to model large scale tactical movement and engagement operations up to brigade level. [Ref. 1:p. 1]

2. Terrain

Janus(A) graphically displays units or systems on a specific two dimensional terrain representation. This terrain representation (map) includes elevation contours, roads, rivers, cities, foliage, engineer barriers, and natural barriers. [Ref. 1: p. 5]

The terrain representation is stored in the Janus(A) database at differing resolutions. The terrain resolution may be tailored to study specific requirements. Janus(A) provides standard terrain resolutions of 12.5, 25, 50, 100, and 200 meter terrain grids. A 600 X 600 cell digital terrain map is displayed on a monitor with terrain map display sizes of 7.5, 15, 30, 60 and 120 kilometers respectively [Ref. 1:p. 6]. For example, at the 12.5 meter resolution, the modeler will see projected on the monitor a map which is 7.5 kilometers by 7.5 kilometers. As the resolution decreases, the terrain map displayed will provide less detail but increased area of the map. Because the 12.5 meter resolution limits the scope of the battle by limiting the size of the battlefield, the lower resolutions, most notably the 50 meter resolution typically are used for simulation purposes.

At the 12.5 meter resolution, Janus(A) calculates heights of elevations every 12.5 meters and at the 100 meter resolution every 100 meters. Thus, a hill which may appear on the 12.5 meter resolution to block the line-of-sight may not appear on the 100 meter resolution. In addition, a valley may also appear at the 12.5 meter resolution and not at the 100 meter resolution.

3. Nodes

Janus(A) uses nodes to define specific routes the systems will traverse. A modeler places an initial node at the point movement originates. Then the modeler uses a puck to move to the next position where the system must change direction and places a node at this point. A line is drawn on the screen from the previously defined node as the puck is moved. The modeler can see whether the route between nodes takes the system through vegetation, over hills, or across rivers. The modeler may add, delete or move nodes as required to establish a desired route for the systems. The modeler uses this procedure to establish a route for each individual system. The modeler can view all of the routes selected for the weapons systems, or for each individual weapons system as desired. The digitized terrain is also used by Janus(A) to determine vehicle movement rates along specific routes. [Ref. 8].

4. Line-of-Sight

Line-of-sight is the ability of a system to detect another weapons system by either using optical or thermal sensors. Janus(A) uses the Night Vision Electro-Optical Laboratory (NVEOL) model for detection [Ref. 7:p. 25]. If a red system is within a blue system field of view and sensor range, an algorithm determines line-of-sight based on terrain, weather, and size of target. If the blue system has line-of-sight with the red system then a detection list is developed for the blue system, based upon input parameters. [Ref. 7:p. 23]

Line-of-sight is significantly affected by terrain features such as hills, valleys, foliage, and man made objects such as buildings. It is also affected by weather, smoke, dust, and the time of day or night. Janus(A) allows the modeler to control each of these variables. However, while Janus can replicate each of these variables to some degree, there will be variability between the operational field test and the model. [Ref. 7:p. 14]

5. Engagements

In Janus(A), engagements can occur once a system has been detected, placed on the detection list, and determined to be within the maximum range of fire for the firing system, assuming the firer has ammunition. Janus(A) uses probability of hit (PH) and probability of kill (PK) data sets for each weapon and target combination. For a specific engagement, the appropriate PH and PK data sets are assessed and interpolated on range. The computed PH and PK are then compared to uniform random number draws to determine the outcome of the engagement. As opposing systems close, the PH and PK values increase so the probabilities of hit or kill also increase. [Ref. 1:p. 2]

B. MODELING THE SCENARIOS IN JANUS(A)

Using map coordinates from Fort Hunter Liggett the matching terrain file from the Janus(A) database was selected and saved. The blue and red systems were placed in the initial positions described in Chapter 1, Section C of this thesis. Routes for Scenario One were those used in the M1A2 EUTE pretest modeling. Each red system's route was built using the procedure described above utilizing nodes.

The second scenario was built by modifying Scenario One. Scenario One was changed so the red force traversed terrain with intervening hills between the blue and the red force (see Figures 1 and 2). Once the red force had navigated around the mountainous terrain, it returned to the original route which passed directly in front of the blue force.

C. SIMULATION CONSTRAINTS

There are several restrictions on the scenarios used in the model.

1. Indirect Fires and Obstacles

Though Janus(A) allows the deployment and employment of systems not requiring line-of-sight, such as aircraft and field artillery, these systems were intentionally left out of the scenarios. Other aspects of the battle, such as placement and minefields or other man made obstructions were not included. Smoke, dust, weather affects were also eliminated. The purpose of placing such constraints on the Janus(A) scenarios was to avoid, where possible, the interference with line-of-sight between weapons systems by elements other than the terrain and the possible effects of the resolution levels.

2. Line-of-Sight

Figures 3, and 4 show line-of-sight limitations in Janus(A). The lines extending from the blue force illustrate line-of-sight for the blue system selected. The dark solid lines are the outer brackets for the field-of-view of the blue system. Breaks in the lines are places where the blue system may not be able to detect other systems. The dotted line above the bottom right corner of the figure is the maximum range of engagement for the blue system.

The 12.5 meter resolution (Figure 3) line-of-sight for the blue system shows breaks in line-of-sight not shown with the 100 meter resolution (Figure 4). Since the 12.5 meter terrain resolution includes greater terrain detail, it may include terrain that the 100 meter resolution does not. This may lead to detections or kills at longer ranges for the 100 meter resolution.

Figure 3 Line-of-Sight 12.5 Meter Terrain Resolution (scale 7.5 kilometers x 7.5 kilometers)

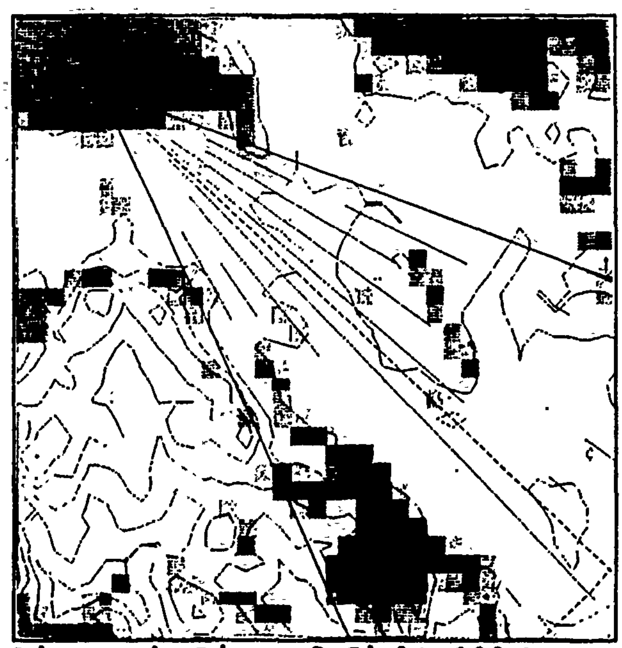


Figure 4 Line-of-Sight 100 Meter Terrain Resolution (scale 60 kilometers x 60 kilometers)

D. JANUS(A) SIMULATION RUNS

Once developed, the simulations were run to insure they worked correctly. A 95% confidence interval for the mean M1A2 range to detection was selected as a basis for determining the number of simulations required to run for the analysis of resolution effects. The sampled populations were not normal, but sample sizes were large enough to allow use of normal distbribution theory, using the Central Limit Theorem [Ref. 9]. The sample size required for the number of simulation runs was determined using the formula [Ref. 10]:

$$n = \frac{Z^2 \alpha/2 \cdot \hat{\sigma}}{L^2}$$

where n is the number of observations, z is a standard normal variable, α is the probability of a type I error, $\hat{\sigma}$ is the point estimate for the standard deviation, and L is the length of the confidence interval, The point estimate of the standard deviation of the M1A2 detection ranges, $\hat{\sigma}$, was based on using data from five simulation runs of Scenario One. The length of the confidence interval, L, was 50 meters. Considering the means for detection ranges ranged from 3000 to 3300 meters, a 50 meter-wide confidence interval is appropriate. Using the formula above the sample size of M1A2 detections for a $(1-\alpha)100\%$ confidence interval of length 50 results in:

$$n = \frac{1.96^2 \cdot 414427}{50^2} = 637$$

For the five simulation runs of Scenario One, the average number of detections per trial was 422. Dividing n by the average number of detections gives the number of simulation runs which are necessary. The calculation 637/422 is 1.51 or approximately 2. Ten simulations runs were made for each route which should provide ample data for statistical analysis.

E. DATA COLLECTION FROM JANUS(A)

After each trial, the Janus(A) Postprocesser was utilized to obtain the data on the MOEs. The postprocesser Direct Fire Report, Coroners Report, and Detection Report generators enable the analyst to collect and save the data for each trial for further analysis. [Ref. 11:p. 58]

F. DATA ANALYSIS

Data were analyzed using the statistical analysis package STATGRAPHICS [Ref. 12]. This software package provides analytical and graphical capabilities.

III. COMPARISONS OF THE MEANS

A. OVERVIEW

The means for the 12.5 and 100 meter terrain resolutions for each MOE were compared in an effort to see if the means were approximately equal. The samples consisted of 10 trials at the 12.5 meters terrain resolution and 10 trials at the 100 meter terrain resolution for Scenario One and 10 trials at each resolution for Scenario Two.

To aid in finding out if terrain resolution did affect the simulations of the two scenarios, three null hypotheses were established and tested. The first hypothesis stated that means for each MOE at the 12.5 meter terrain resolution is equal to the mean at the 100 meter terrain resolution. The second hypothesis stated that the means for each MOE were equal for the two scenarios. The third hypothesis stated that there is no interaction between the scenario and the resolution factors.

Analysis of each sample using STATGRAPHICS' Summary Statistics option showed that the data were not normally distributed. A two-way analysis of the variance (AOV) was employed for data analysis. In using this procedure one assumes normality of the samples, however, the two-way AOV is known to be quite robust with respect to departure from normality [Ref. 13:p. 43].

Homogeneity of variance for each MOE was analyzed. Where numerical counts were involved, as with the MOEs Shots to Kill and Shots on Target, transformations were performed to stabilize the variance [Ref. 13:p. 232].

B. INDEPENDENCE OF DATA

Data from different runs of Janus(A) are assumed to be independent.

C. RESULTS

Results of the analyses showed that for four of the five MOEs, a minimum of two of the three hypotheses failed to be rejected. The results of the analysis using Range to First Engagement as an MOE indicated all three hypotheses should be rejected. A more detailed discussion of the results follows.

1. Range to First Detection

The AOV results showed no significance for any of the hypotheses, see Table III.

TABLE III COMPARISON OF THE MEANS FOR RANGE TO FIRST DETECTION

ANALYSIS OF THE VARIANCE RANGE TO FIRST DETECTION					
Source	df	ss	ms	F	sig. level
Resolution	1	.0004096	.0004096	.021	.8880
Scenario	1	.0200704	.0200704	1.013	.3209
R x S	1	.0577600	.0577600	2.916	.0963
Error	36	.7131420	.0198095		

The lack of significance for these hypotheses may tend to lead the modeler to reject the notion that Range to First Detection would be affected by the terrain resolution. The results also showed that there apparently was very little interaction between Scenario and Resolution. Section C of Chapter II illustrated possible differences in line-of-sight for the 12.5 and 100 meter terrain resolutions. For these simulations it was possible that line-of-sight had no affect on the results of the simulation runs of the two scenarios because of the flatness of the terrain at the range the systems were detected.

Scenario One and Scenario Two had the same initial coordinates for the red force. At this location there was relatively flat terrain and the red force was within the maximum detection range of the blue force. The flatness of the terrain combined with the close initial proximity of the red force to the blue force may have allowed the blue force to attain line-of-sight and detection of the red force. This might explain the similarity of the means at the 12.5 and 100 meter terrain resolutions, as well as the equality of the means between scenarios.

2. Range to First Engagement

Results of the AOV for this MOE indicated that each of the three hypotheses showed significance, see Table IV.

TABLE IV COMPARISON OF THE MEANS FOR RANGE TO FIRST ENGAGEMENT

ANALYSIS OF THE VARIANCE RANGE TO FIRST ENGAGEMENT					
Source	df	ss	ms	F	sig level
Resolution	1	.0736164	.0736164	6.314	.0166
Scenario	1	.3996001	.3996001	34.273	.0000
R x S	1	.1067089	.1067089	9.152	.0046
Error	36	.4197370	.0116594		

The results of the AOV show significant interaction between Scenario and Resolution. Figure 5 is a plot of the interaction between Scenario and Resolution. The numbers on the curves denote the scenario. The graph indicates the nature of the interaction between Resolution and Scenario.

One-way AOVs, equivilant to t-tests, were conducted for each scenario using the hypothesis of equal means for the range to first engagement between 12.5 meter and 100 meter terrain resolutions. The results of the AOV for Scenario One showed there was no significance. However, there was significance for Scenario Two. The mean range to first engagement for the 12.5 meter resolution for Scenario Two was 2,876 meters while the mean range to first engagement for the scenario at 100 meter terrain resolution was 2,680 meters. meters.

Because of the greater level of terrain detail at the 12.5 meter terrain resolution, which might limit or enhance line-of-sight, the mean ranges to first engagement at the 12.5

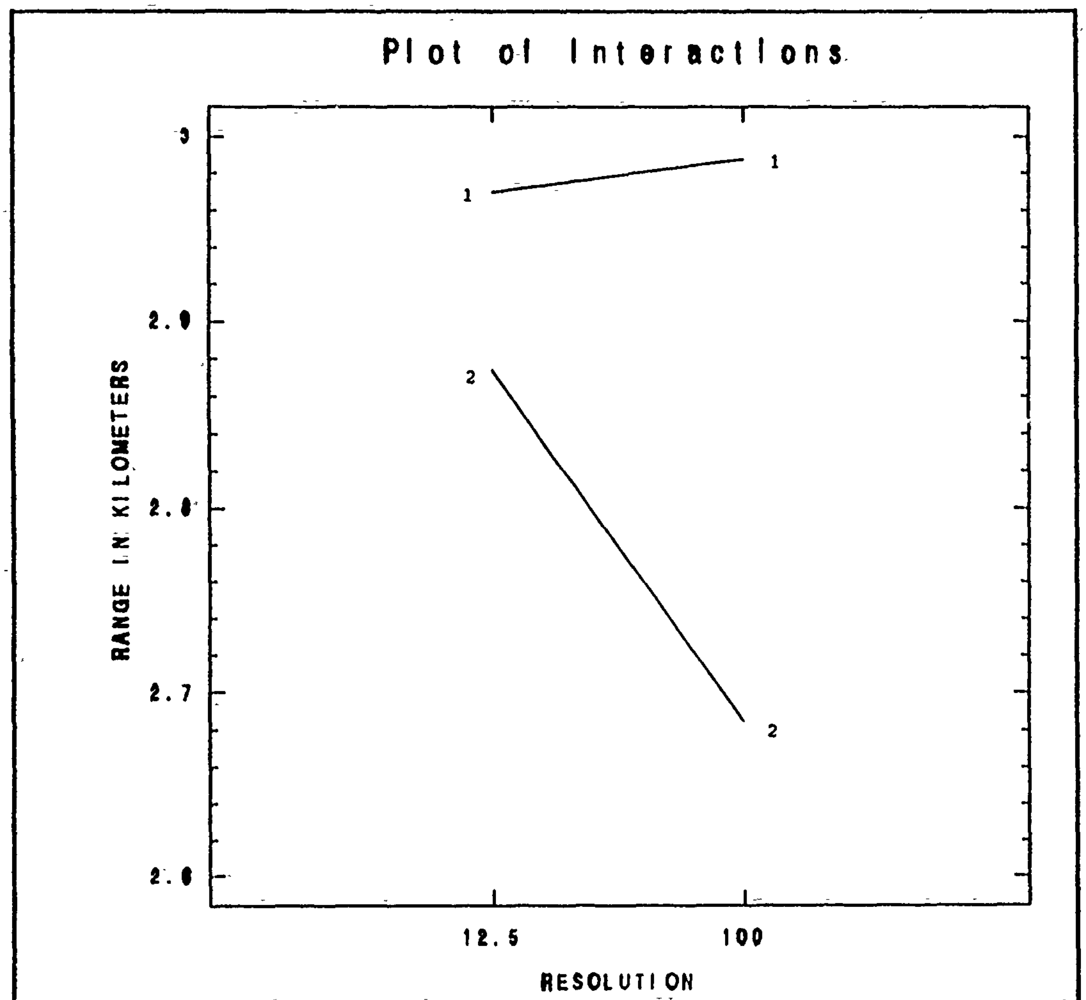


Figure 5 Interaction of Resolution and Scenario Range to First Engagement

meter terrain resolution could have been either closer to or farther from the blue force than at the 100 meter terrain resolution. Figure 6 illustrates the difference in the mean range to the first engagement for scenarios one and two. The route of advance of the red force behind the hills in Scenario Two appeared to have screened it from the blue force, whereas the red force in Scenario One was not protected by the terrain as it advanced along flatter terrain. This may explain why the range to the first engagement was lower for Scenario Two.

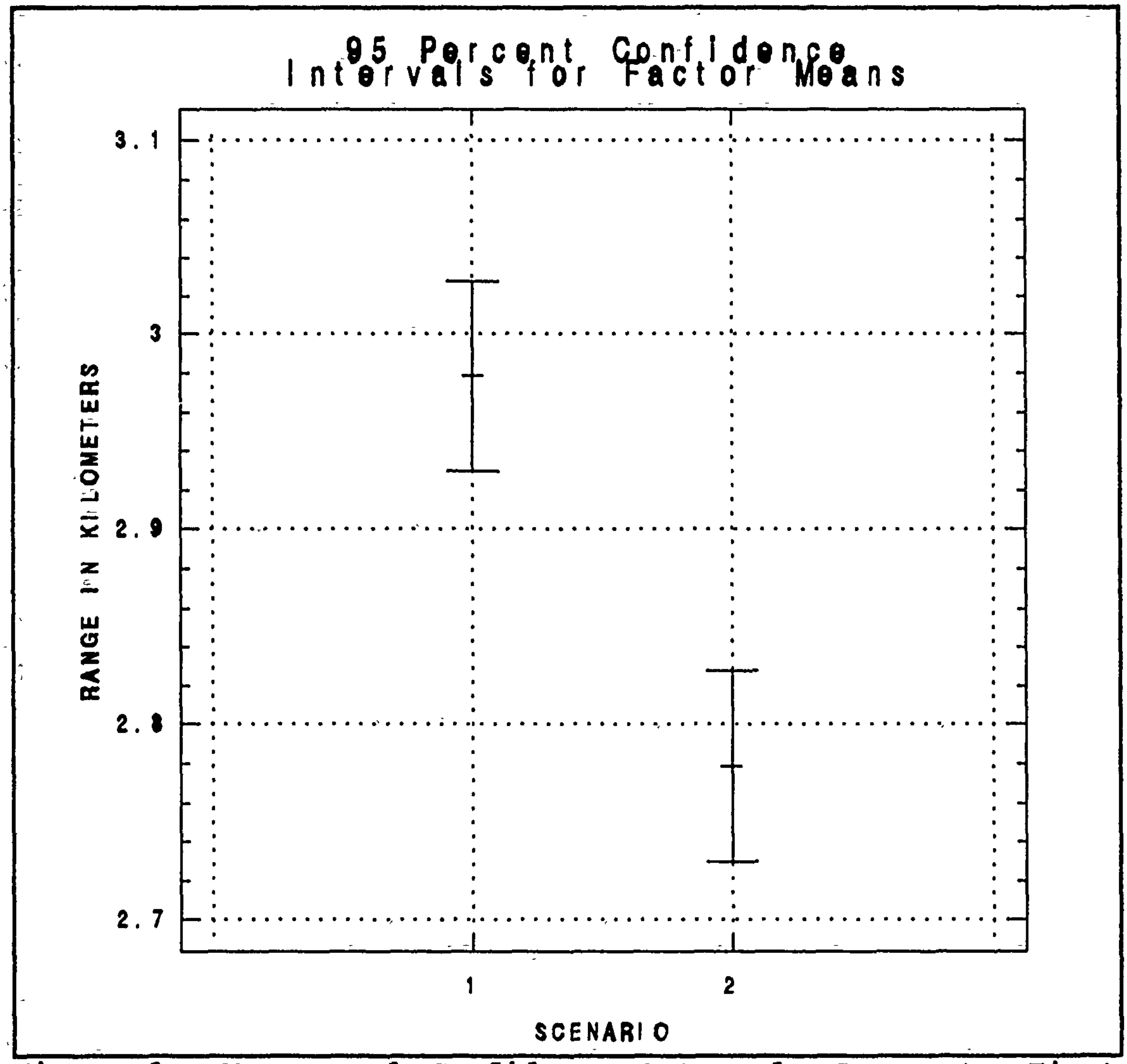


Figure 6 Means and Confidence Intervals Range to First Engagement, by Scenario

3. Range to First Kill

Results of the AOV indicated significance for only the hypothesis of equal mean range to first kill for the two scenarios, see Table V.

TABLE V COMPARISON OF THE MEANS FOR RANGE TO FIRST KILL

ANALYSIS OF THE VARIANCE RANGE TO FIRST KILL					
Source	df	ss	ms	F	sig. level
Resolution	1	.1281424	.1281424	2.312	.1371
Scenario	1	.3964081	.3964081	7.154	.0112
R x S	1	.0225625	.0225625	.407	.5342
Error	36	1.9948814	.0554134		

The first and third hypotheses were not significant. The means were approximately equal at the 12.5 and 100 meter terrain resolutions. No significant interaction was found. While Section C, Chapter II showed that line-of-sight may vary be resolution, for this MOE the red force was in line-of-sight of the blue force at the same range for each terrain resolution, resulting in similiar means. For the simulations which were run, line-of-sight was achieved at both the 12.5 and 100 meter terrain resolutions at the approximately the same mean range. If line-of-sight had been significantly affected by the terrain resolution, the result should have shown that the mean range to first kill at the 12.5 meter terrain resolution was not equal to the mean range for first kill at the 100 meter terrain resolution.

When compared by scenario, the mean ranges to first kill were quite different, and the second hypothesis should be significant. Range to first kill for Scenario One was 2,860 meters while for Scenario Two it was 2,661 meters. As one might suspect based upon the terrain, Scenario Two's mean ranges to first kill were shorter than Scenario One's. The terrain of Scenario Two may have limited line-of-sight for the blue force resulting in the shorter ranges to the first kill for Scenario Two.

4. Shots to Kill

Shots to Kill differs from the previous MOEs in that it is a numerical count rather than a range. Since this MOE's distribution was possibly geometric in nature a square root transformation was performed. The results of the AOV for the MOE square root Shots To Kill indicated no significance for two of the three null hypotheses, see Table VI.

TABLE VI COMPARISON OF THE MEANS FOR SHOTS TO KILL

ANALYSIS OF THE VARIANCE SQUARE ROOT OF SHOTS TO KILL					
Source	df	ss	ms	F	sig. level
Resolution	1	.4185911	.4185911	.390	.5427
Scenario	1	.49912106	.49122106	4.654	.0377
R x S	1	.0010973	.0010973	.001	.9750
Error	36	38.606336	1.0723952		

The mean square root shots to kill 12.5 meter terrain resolution was not significantly different from that for the 100 meter terrain resolution. If the blue force had the same line-of-sight at the same ranges for each simulation run, thus having provided the same shot opportunities, then similiar means could have resulted. This result would indicate that terrain resolution may have had little affect on mean shots to kill for the two scenarios.

As in the previous MOE, the second hypothesis was significant. The mean number of shots to the first kill for Scenario Two was significantly fewer than for Scenario One (2.9 shots vs 2.3 shots). If the number of engagements for Scenario Two occurred closer to the blue force than for Scenario One, the probabilities of a hit or kill would be higher. The high probability of a kill may explain the lower number of shots expended in the Scenario Two simulation runs. This reasoning would suggest that the terrain in Scenario Two may have caused limited line-of-sight of the blue force.

5. Shots on Target

Shots on Target is also a numerical count. This MOE may have had a poisson-like distribution. A transformation was performed by taking the logarithm of shots on target. The transformation stabilized the variance and tests of the three null hypotheses were made using AOV. The AOV indicated none of the three hypotheses was significant, see Table VII.

TABLE VII COMPARISON OF THE MEANS FOR SHOTS ON TARGET

ANALYSIS OF THE VARIANCE LOG (SHOTS ON TARGET)					
Source	df	ss	ms	F	sig. level
Resolution	1	.5063423	.5063423	1.031	.3167
Scenario	1	.0410580	.0410580	.084	.7772
R x S	1	.9366936	.9366936	1.098	.1754
Error	36	17.676694	.4910193		

The 12.5 meter terrain resolution's mean for shots on the target destroyed first was approximately the same as for the 100 meter terrain resolution. The blue force may have had line-of-sight of the red force at nearly the same ranges for each simulation run. If line-of-sight existed at the same range then it is possible that the target was shot at approximately the same mean number of times regardless of the resolution. When compared by scenario, the mean log (shots on target) for Scenario Two was not different from the mean for Scenario One. There was no intereaction between Resolution and Scenario.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSION

There is very little evidence suggesting terrain resolution significantly affected the outcomes of the Janus(A) simulation runs for the deliberate defense scenario using Fort Hunter Liggett terrain. The data from simulations of two scenarios at 12.5 and 100 meter terrain resolutions was examined. Only for one MOE, Range to First Engagement, did the results of analysis indicate rejection of each of the three hypotheses of equal means.

The question remains whether there is a difference in the outcome of simulation runs using the 12.5 meter terrain resolution versus using the 100 meter terrain resolution. The 12.5 meter terrain resolution is used to provide greater terrain detail though using it sacrifices the size of the terrain map displayed by Janus(A). Using 100 meter terrain resolution gives less terrain detail and provides a larger terrain map display. Using the 12.5 meter terrain resolution may not result in significantly closer ranges of detection, engagement and kills than using the 100 meter resolution even if the terrain has terrain features such as hills, valleys, foliage, etc. For the deliberate defense scenarios considered here, the terrain resolutions were not associated with significant differences in the MOE means, except for the Range to First Engagement, even with two scenarios having greatly differing terrains.

B. RECOMMENDATIONS

The analyses of the Range to First Engagement data indicated there might be some affect related to levels of terrain resolution. The indication that there is some difference using 12.5 versus 100 meter terrain resolution, though, warrants further investigation.

In the introduction mention was made of the availability of a 1 meter database of the Fort Hunter Liggett terrain. There is great interest at TRAC-MTRY in determining the optimal level of resolution for modeling purposes. The interest stems from the concern that the Janus(A) terrain database may not adequately replicate the actual terrain on which the operational field tests take place [Ref. 3:p. 1]. Hills, valleys, and foliage that actually exist are not represented in the Janus(A) terrain database, nor are the effects of man and time on the physical attributes of the terrain.

The comparison between 12.5 meter and 100 meter terrain resolutions did not show a great affect on the results of the simulation runs which were considered. However, a comparison of 1 meter and 12.5 meter terrain resolution might show differences that were not found in this thesis. Possibly other MOE's should be considered in addition to those used here. Further investigations should be made of the affects of levels of terrain resolution on other scenarios, possibly with finer levels of resolution. This should include the 1 meter Fort Hunter Liggett database, when it becomes available in Janus(A).

REFERENCES

1. Kellner A., "Janus(Army) Version 2.0," March 1991.

2. East, A., Comparison of Tank Engagement Ranges From An Operational Field Test to the JANUS(A) Combat Model, Master's Thesis, Naval Postgraduate School, Monterey, CA, September 1991.

3. Paulo, G., "Real World Perspective/1M Database Integration Into Janus," TRADOC Analysis Command, Monterey, CA, February 1992.

4. Hollis, Walter W., Verification and Validation (V&V) and Accreditation of Models, Department of the Army, Office of the Under Secretary, Washington, D.C., October 1989.

5. Bundy, D., Generic Model-Test-Model Using High Resolution Combat Models, AORS XXX Proceedings, Vol. I, November 1991.

6. Bundy, D., and Paulo, G., Model-Test-Model Efforts in Support of M1A2 EUTE, unpublished.

7. Pimper, Jeffrey E. and Dobbs, Laura A., Janus Algorithm Document, Lawrence Livermore National Laboratory, Livermore, CA, January 1988.

8. Design/Development Team, Janus Version 4.0 Users Manual, pp. 3-7, Lawrence Livermore National Laboratory, Livermore, CA, January 1988.

9. Conover, W. J., Practical Nonparametric Statistics, John Wiley & Sons, 1980.

10. Newbold, Paul, Statistics for Business and Economics, Prentice Hall, 1988.

11. Bundy, D., "JANUS(A) Basic User's Tutorial," TRADOC Analysis Command, Monterey, CA, unpublished.

12. Statistical Graphics Corporation, STATGRAPHICS, Statistical Graphics System, STSC, Inc., 1991.

13. Box, Hunter, Hunter, Statistics for Experimenters, John Wiley & Sons, Inc. 1978.

DISTRIBUTION LIST

Deputy Director for Force Structure R&A, J-8 Office of the Joint Chiefs of Staff Room 1E965, The Pentagon Washington, DC 20310-0401	1
HQDA Office of the Technical Advisor Deputy Chief of Staff for Operations and Plans ATTN: DAMO-ZD Room 3A538, The Pentagon Washington, DC 20310-0401	1
Director US Army TRADOC Analysis Command-WSMR ATTN: ATRC-WSL (Technical Library) White Sands Missle Range, NM 88002-5502	1
Director US Army TRADOC Analysis Command-Ft. Monroe ATTN: ATRC-RP Fort Monroe, VA 23801-6000	1
Rand Corporation ATTN: Tom Herbert (MOSF) 1700 Main Street PO Box 2138 Santa Monica, CA 90406-2138	1
Director US Army Material Systems Analysis Activity ATTN: AMXSY Aberdeen Proving Ground, MD 21005-5071	1
US Army Combined Arms Research Library (CARL) ATTN: ATZL-SWS-L Fort Leavenworth, KS 66027	1

Defense Technical Information Center 2
ATTN: DTIC-TCA
Cameron Station
Alexandria, VA 22304-6145

US Army Library 1
Army Study Documentation and Information Retrieval System
ANRAL-RS
ATTN: ASDIRS
Room 1A518, The Pentagon
Washington, DC 20310

HQDA 1
DUSA-OR
ATTN: Mr. Walter W. Hollis
Room 2E660, The Pentagon
Washington, D.C. 20310-0102

Commander 1
U.S. Army Training and Doctrine Command
ATTN: ATAN-ZB
Fort Monroe, Virginia 23651-5143

Commander 1
U.S. Army TRADOC Analysis Command
ATTN: ATRC
Fort Leavenworth, KS 66027-5200

Deputy Commanding General for Training 1
Combined Arms Command
ATZL-CT
Fort Leavenworth, KS 66027-7000

Commanding General 1
National Training Center and Fort Irwin
Fort Irwin, CA 92310-5000

Commander 1
U.S. Army TRADOC Analysis Command
ATTN: ATRC-TD
Fort Leavenworth, KS 66027-5200

Director 1
Study and Analysis Center
ATTN: ATRC-SAT
Fort Leavenworth, KS 66027-5200

Director 1
Scenarios and Wargaming Center
ATTN: ATRC-SW
Fort Leavenworth, KS 66027-5200

Director 1
Operations Analysis Center
ATTN: ATRC-F
Fort Leavenworth, KS 66027-5200

Director 1
U.S. Army TRADOC Analysis Command-WSMR
ATTN: ATRC-WE
White Sands Missile Range, NM 88002-5502

Director 1
U.S. Army TRADOC Analysis Command-WSMR
ATTN: ATRC-W
White Sands Missile Range, NM 88002-5502

Director 5
U.S. Army TRADOC Analysis Command-Monterey
ATTN: ATRC-RDM
P.O. Box 8692
Monterey, CA 93943-0692

Director 1
U.S. Army TRADOC Analysis Command-Ft. Benjamin Harrison
ATTN: ATRC-FB
Fort Benjamin Harrison, IN 46216-5000

Director 1
U.S. Army TRADOC Analysis Command-Fort Lee
ATTN: ATRC-LEE
Fort Lee, VA 23801-6140

Director 1
U.S. Army TRADOC Analysis Command-Los Alamos
P.O. Box 1663 (Mail Stop F605)
Los Alamos, NM 87545

Chief 1
ARI Field Unit
P.O. Box 5787
Presidio of Monterey, CA 93944-5011

Lawrence Livermore National Laboratory 1
ATTN: TRAC-LL
P.O. Box 808 L-315
Livermore, CA 94550

Director 1
Conflict Simulation Center
Lawrence Livermore National Laboratory
P.O. Box 808 L-315
Livermore, CA 94550

Commander 1
Operations Group
ATTN: ATZL-TAL-O
Fort Irwin, CA 92310-5000

Director 1
CALL
ATTN: ATZL-TAL
Ft. Leavenworth, KS 66027-7000

Commandant 1
U.S. Military Academy
ATTN: Department of Systems Engineering
Bldg 752, 4th Floor
West Point, NY 10996-1779

U.S. Army Operational Test and Evaluation Agency 1
ATTN: CSTE-ZTM
Suite 1060, 4501 Ford Avenue
Alexandria, VA 22302-1458

Technical Information Center 1
HQs, TRADOC Test and Experimentation Command
Experimentation Center (Bldg 2925)
Fort Ord, CA 93941-7000

Library, Code 52 2
Naval Postgraduate School
Monterey, CA 93943-5002

Director 1
U.S Army Concepts Analysis Agency
8120 Woodmont Ave.
Bethesda, MD 20814-2797

U.S. Army Combined Arms Research Library (CARL) 1
ATTN: ATZL-SWS-L
Ft. Leavenworth, KS 66027

U.S. Army Library 1
ATTN: ANR-AL-RS (Army Studies)
Room 1A518, The Pentagon
Washington, D.C. 20310-6010

Professor Donald Barr 1
Code MA/Ba
Naval Postgraduate School
Monterey, CA 93943-5002

Professor Tung Bui 1
Code AS/Bd
Naval Postgraduate School
Monterey, CA 93943-5002